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SHIP CANAL LOCKS CALCULATED FOR OPERATION BY STEAM.

By Ashbel Welch, Member of the Society.

Read at the Twelfth Annual Convention, May 25, 1880.

So few canals have been built, and so many of those already built have been abandoned, during the last thirty or forty years, that very few engineers have considered them at all worthy of their attention. The few that have studied their construction and operation, have seldom published the results of their study, for nobody was sufficiently interested to read anything on the subject.

Recently, however, the project now seriously entertained, and which may sooner or later be executed, of making a canal across the great American Isthmus, has awakened a deep interest in this long neglected but now important subject.

I consider it due from the older engineers who have had experience in it, and have kept up their interest in it, to give the results to their professional brothers.

The great advantages of railroads over canals of ordinary dimensions, except to make short connections between existing water routes or harbors, or in some very exceptional circumstances, will doubtless continue in the future, as in the past, to prevent their construction. But short ship canals connecting ocean routes, many thousands of miles in length, will be sure to be built hereafter. The great difficulty in the way of making such canals, is the locks, or the enormously expensive, dangerous and every way objectionable deep cuts made to avoid them. A proposition to obviate, or lessen the objections to such locks is therefore now opportune.

In order to a full view of this subject, it will be necessary to repeat some things I have said on former occasions at the meetings of this Society in New York. But as some details now proposed vary from those then contemplated, some dimensions and calculations will vary from those then presented.

In ordinary locks of former times, the strength of a man was sufficient to open and shut the gates, valves and wickets. The team of horses or mules could haul the boats in and out. When steamers came they could move themselves in and out. If they glanced against the walls, their weight was not such as to make the collision very injurious.

But in locks large enough for ships, all this is different. Men cannot open and shut the main gates, or the feeding and discharging gates in any reasonable time. Quadruped power cannot haul a ship in or out. Capstans and windlasses worked by men can haul them only slowly and laboriously. Lines light enough to be handled by men will not hold a ship safely. Steam on board acting against unstable water, is not certain enough, or quick enough, or controllable enough, to be trusted. A slight collision against the walls might indent, or even break the skin of a ship.

In my younger days I had charge of the Delaware and Raritan Canal, where the locks and vessels were so large that the working of the one by

hand, and hauling of the other by animals, was always a source of delay, and sometimes of accident. Lock tenders, vessel's crews, and team drivers, commonly inexpert at best, often failed to act in concert, especially in the night and in the storm. At a very early period I contemplated the application of a power to operate the locks and haul the vessels, which had become a well matured, well trained and obedient servant to the human will, the steam engine; not afloat, but stationary on the wall of the lock. A dozen years ago, in 1868, the canal having reached the limits of its locking capacity (though I had then no special charge of the canal, more than all the other works between New York and Philadelphia), I applied the steam power at the locks, thirteen in number, and at once increased their capacity, and, therefore, that of the canal, fifty per cent. Accidents, not infrequent before, are, so far as I know, unheard of since. It is still in operation, and its success is complete. The apparatus is so safe and so strong, that I never heard of anything getting out of order or breaking during the dozen years it has been in use.

The engine has two cylinders, each 6"x12", turning a drum 3 ft. in diameter, which moves an inch wire rope 2 200 ft. long, passing around sheaves above and below the lock, and passing over rollers along the face of the lock. The vessels are attached to this by short lines. The rope moves half as fast as the piston. The greatest strain ever put on the rope is rather under 6 000 pounds. The weight of the two boats, hauled in together, sometimes reaches 2 000 000 pounds. The engine also opens and shuts the gates, and works the valves by which the lock is filled. It also, in one case, turns a swinging bridge near the lock, on a much travelled road in a city, in a quarter of the time it previously took to turn it by hand.* I carefully calculated all the powers, resistances, strains, and strength beforehand. Though much thought was expended upon it, the whole apparatus when done is "ridiculously simple."

The full advantage of steam cannot be availed of in working existing locks, or locks made after old models, for they are not calculated for it. We must then make bold and radical changes, and adopt new arrangements by which that power can be used to the best advantage.

My present object is to point out how a ship canal lock of the most

*The engine and machinery were made by Mr. William Cowin, at the Lambertville Iron Works, the details arranged by Mr. William Johnson, the mechanical expert at those works. The ropes were made and advice given as to their strength and management, by Mr. John A. Roebling.

extreme dimensions, and of 30 feet lift, can be made, into and out of which ships of the largest size can be hauled quickly, and in which they can be held and handled safely, and all the operations of the lock performed surely and rapidly by a steam engine on the wall.

This mighty agent in its present matured state, so powerful, so controllable, so instantaneously, and so exactly obedient to human command, can with suitable appliances, which I propose to point out, be made to perform all the haulings and holdings of the ships, and all the openings and shuttings of the gates and valves, safely, certainly and quickly.

Water power cannot so well be applied directly, for its changes are not quick enough, but it may be applied through hydraulic engines with great advantage.

It appears from the advice they have given, that some of the most eminent engineers of the world have not thought of this plan, or at any rate, have not thought it out, and that for want of considering what can be done, and knowing what has been successfully done already, they, as well as most persons interested in ship navigation, including naval officers, consider locks for ship canals absolutely inadmissible. I repeat what I have already said on more than one occasion, that if locks for ships could be operated only in the old way, I would no more build one than undertake to row the *Great Eastern* across the Atlantic by human hands. Knowing only the old way, those engineers were right in advising a level canal from the Atlantic to the Pacific, notwithstanding its enormous cost, its unavoidable narrowness involving great delay and risk, its exposure to floods only imperfectly diverted, and all the dangers and expenses almost always incident to deep cuts.* Some of those risks I adverted to more fully on a former occasion.

I do not claim that the precise plans and arrangements I propose are the best possible. I wish rather to present what is simple, and unmistakably practicable, than what may be really better, but the practicability of which is not so evident. An expert mechanic could, doubtless, improve upon some of the details of my machinery; if so, the argument in favor of the general plan is all the stronger. If the apparatus, as

*The Chesapeake and Delaware Canal has a deep cut about a mile long—I don't know the figures, but I suppose that first and last the maintenance of the canal through this cut has cost more than the maintenance and operation of all the locks on the canal. The "Gap Cut" on the Pennsylvania Railroad gave a great deal of trouble for years and cost a good deal of money.

presented, will answer the purpose well, much more will it when made more perfect.

The first thing to be done is to get out of the old grooves, and into sympathy with the age; to forget precedents established in other countries, under circumstances entirely different, when all was on a small scale, and before the arts now applicable had grown to maturity. Plans all right for the little canal of Languedoc, two centuries ago, are not good precedents for a ship-canal in America in 1880. When they talk of canals, eminent engineers seem to have forgotten, or rather not to have taken the time to apply the originality, skill and ingenuity that they have applied to everything else.

I am indebted for some of the ideas now to be presented to the experience of my old friend, Edwin A. Douglas, on the upper Lehigh. It was his good fortune to know little and care less about old rules and precedents.

Sketch No. 1, Plate XII., shows the general ground plan, on a small scale, of a lock 680 feet long, with chamber 600 feet by 80 feet, with a channel on one side to bring the water, which I shall call the inlet channel, and a channel on the other side to carry it away, which I shall call the outlet channel. Where it is possible the water should come into and go out of these channels not from the canal immediately above and below the lock, but from and to some expansions of the canal, or reservoirs outside of it, away from the lock, so as always to avoid any current near the lock. The prism of the canal should be enlarged and deepened immediately above and below the lock, so that vessels can be moved with the least resistance and most certainty. Racks should be used where the water is admitted into the reservoir, or inlet channel, to exclude floating wood or brush.

This plan contemplates two water ways at right angles to each other, one for the passage of vessels only, longitudinally through the lock, the other for the passage of water only, transversely to the axis of the lock, first through one wall to fill the chamber, then through the other wall to empty it.

This avoids the principal sources of expense in maintaining the lock itself, the wickets in the movable gates, and the collisions and rough contacts of vessels with gates caused by longitudinal currents produced by filling from one end, and emptying at the other. It also avoids the injury to vessels from collisions caused by those same currents. In filling

and emptying through the sides, the openings should be so spaced as to cause no longitudinal current in the chambers.

Where lock gates are opened and shut by human muscle, the temptation always exists to let on a little water, and let its pressure aid the operation. This brings the gates against the mitre sill with a slam, and if they do not come shut at the same moment, often twists, sometimes unships them. Where the gates are opened and shut by steam, without human effort, there is no temptation to do this. There is little else about a lock that ever needs repair.

I have calculated for a lock of these extreme dimensions, 600 feet by 80 feet chamber, and 30 feet lift, to show how easy it is, if you have plenty of water, to pass the largest ships safely and quickly; and though the cost of construction and operation are very great, they are very little in comparison with the amount saved by them.

Where there is not plenty of water, the lock should be narrower, and water-saving basins made as pointed out hereafter.

Floats, not solid walls or wharves, should form the approaches. Large ships should not be allowed to touch solid walls or the lock gates, and commonly not even the floats.

I have calculated for a lift of 30 feet. Probably that is as high as the ground will permit any lock to be made. I should not hesitate to go higher than that if the situation permitted.

Where there is plenty of water, or where water-saving basins are used for the locks of large lift, there is no necessity for the traditional Procrustean rule of making the locks of uniform lift whether that fits the ground or not. Mr. Douglass, already mentioned, made locks of 33 feet lift, which worked easily, safely and well for a quarter of a century. They were emptied in two minutes. The higher the lift, the less the cost of construction and operation, and the less the detention, per foot lift.

In making a lock on the plan I propose, the one vital part requiring the most special care is the foundation platform. A lock foundation has two duties to perform; first, to distribute and sustain the weight without settling, or settling unequally; and, second, to hold the water *upon*, and not to allow any of it to get *under*, the platform.

On anything but sound, solid rock, an artificial foundation is, of course, necessary.

If the rock is suspected to be cavernous, it should be bored, and

PLATE XII
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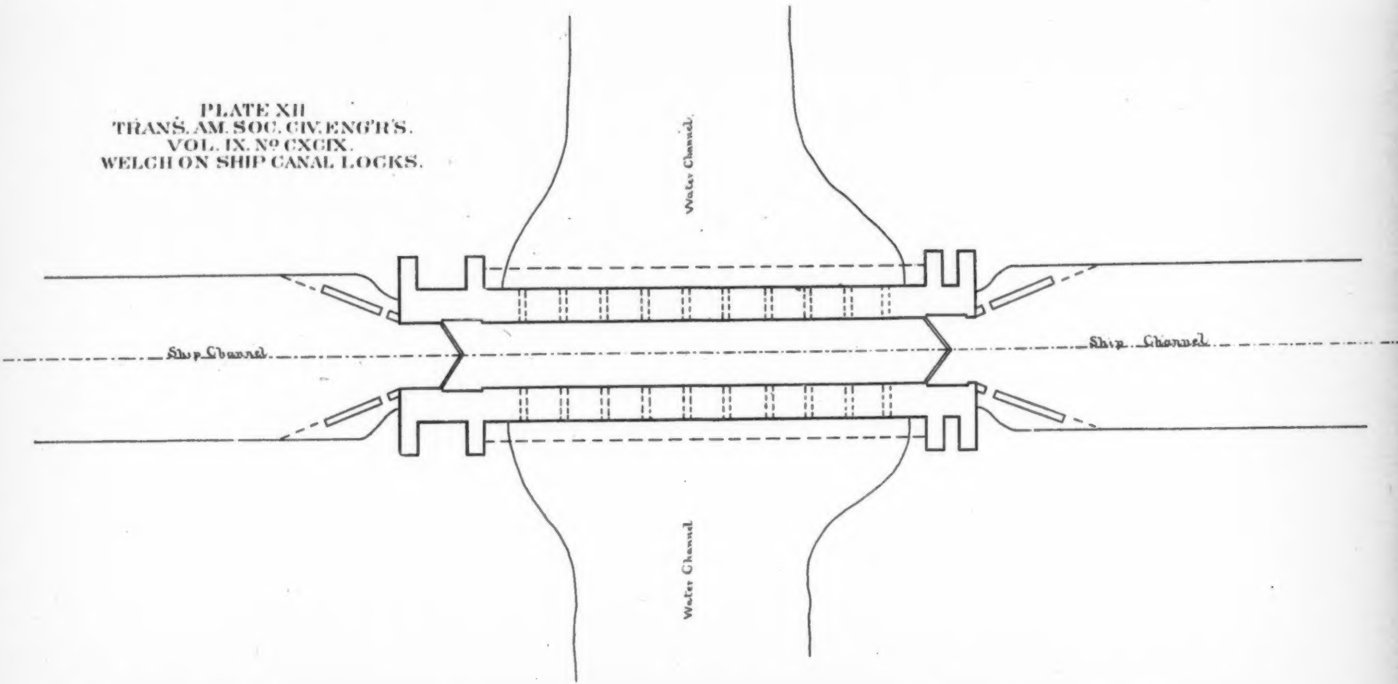

if small cavities are found, they may be filled with grout, the water rising through a second hole bored into each cavity. The holes should, of course, be carefully filled. If the rock is seamy, it should be taken out a foot or two deep, the seams cleaned out and grouted, and the whole surface covered with a stratum of concrete.

If the bottom is anything but rock, hard-pan, gravel, or clean sand, or some other incompressible soil, with the great weight required by this plan to be put upon it, it should be piled. Clay should not be trusted; it compresses unequally. The piling should not only be under the walls, but under the water-spaces as well, for in a ship-canal lock of 30 feet lift, the pressure on the bottom of the chamber will vary from nearly a ton on the square foot to double that pressure. The length and number of piles must depend on the circumstances of each case, and be governed by rules already well understood.

For such a lock the foundation platform should consist of, first, a stratum of the best concrete not less than 18 inches or two feet thick, and on it (and upon, not between the piles, if there are any, unless under the walls) long stiff hard wood timbers, flatted out of wind, smooth on the top, 18 inches deep, should be placed transversely covering the whole space under the walls and under the mitre sills, two-thirds or three-quarters of the space between the walls. The interstices between the timbers should be perfectly filled with concrete, or where too narrow to get it in, with grout. The timbers should break joints so as to have as far as possible the same effect as if they extended all the way across the foundation.

The covering on these timbers laid parallel to the axis of the lock, should be, under the walls, jointed timbers of hard wood 12 inches thick, and under the water spaces 4-inch carefully jointed white pine plank.

White (not yellow) pine is the best for this purpose of anything I know. It swells when wet, and remains swelled under water, so that it prevents leakage at the joints, while it is so compressible that the swelling can with proper care be prevented from bulging up the floor. When put in it should be as much as half seasoned, and in that case, wedged together very hard; if fully seasoned, not very hard. When laid, the concrete and timber should be covered with a little thin mortar to ensure a perfect contact between the floor plank timber and concrete, and freedom from any minute interstice which is liable to become a water channel. I have always found wood and cement together much safer to

hold water than either separately. The cement stops an open joint, crack, worm-hole, or knot-hole in the wood; the wood does not allow the water to reach a crack or defect in the concrete. The cement under even very thin plank saves it from wearing in the joints by a strong current upon it. The union between cement mortar or grout and timber is very perfect.

Whether spikes are used or not, the floor should be tree-nailed to the foundation timbers. The tree-nails should be of white oak or other tough, hard wood, turned, not shaped with the axe, but turned, 20 inches long, $1\frac{25}{32}$ diameter, following an inch and three-quarter angle, the 4 inches through the plank tapered so as to be a quarter of an inch larger at the outer end. This prevents the tree-nails from drawing through the plank; there is no danger of their drawing out of the timber. I used this plan for many years. In former days many thought square tree-nails in soft wood held best, but it was a mistake. The grain of wood should be compressed, but never broken or crushed; that destroys its holding power.* Besides, there is danger of open spaces along the flat side, in which the water whirls and cuts. The object of tree-nails which offer so much more surface than spikes or bolts against the fiber of the wood to resist the sliding of one piece of timber or plank over another, is to prevent the floor planks from crawling, and thus breaking loose from the concrete underneath, For a similar reason I have always used tree-nails in the bracing of timber trestles for railroads. I am thus minute, because in this matter few engineers have had experience, and the foundation platform is the all important, and the one difficult thing to execute. This is one of the cases where success depends very much on practical details.

If the material under the concrete is clay or anything softer, I would cover it with a foot or two of gravel under the concrete. Otherwise if a film of water should get to running under the concrete and in time wear off some of the clay, it would leave a cavity which might increase and in time become dangerous. But with the gravel, which drops into and fills up the minute channel immediately, its enlargement is prevented, and the film of water is either stopped or runs harmless over the gravel. Most of the failures I have known in anything from the action of water, have originated in this operation on clay. A driblet of water following

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* For this reason ragged spikes, as I have found by experiment, do not, in many cases, hold as well as plain.

PLATE XIII.
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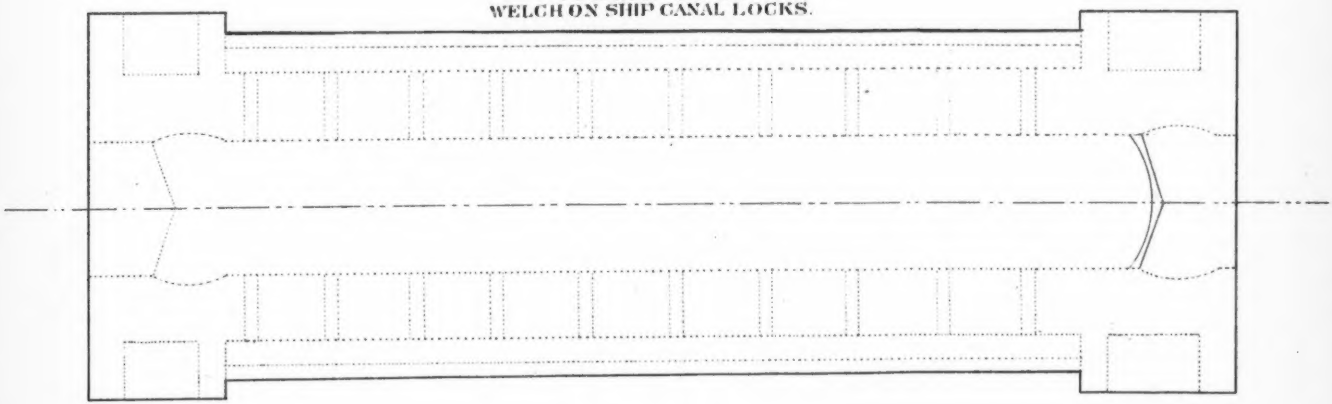

a rootlet gradually forms a channel, the clay instead of falling together like gravel, arches over, a water course is formed and disaster follows.

I suppose European engineers would reject my wooden platform with scorn. If they had our American experience they certainly would not. The stratum of concrete alone is not safe, it may crack ; the plank platform alone is much safer, but in connection with the concrete as near absolutely certain as any man-made structure can be. I would as soon think of dispensing with wooden cross-ties for a railroad, and going back to stone blocks, as dispensing with the timber platform.

If the water is brackish it may be necessary to cover the whole floor with a stratum of cement and coarse sand a few inches thick to protect it from the teredo.

Under the outside of the platform along both sides and across the head and foot, under the mitre sills, I would build, if not on rock, a continuous wall of concrete or grouted masonry, 4 feet to 6 feet thick, and 6 feet to 12 feet deep, or where the soil is not water-tight even 20 feet deep, according to circumstances, with 4-inch sheet pilings on the side from which water may come, the contact of wood and wall being made perfect by mortar and grout. Other stop-water walls and sheet-pilings may be built, especially longitudinally under each main wall, where there is any possible danger.

The continuity of the floor should be absolutely unbroken over the whole space. This excludes stone mitre sills, which I would not use in any case. Wood or iron are much better. In building on rock, I would excavate three or four feet extra depth, under the swing of the main gates across the chamber between the lower recesses, so as to enable the water to pass under as well as around the gates from one side to the other, and thus make them swing more easily. But I would not make a break or offset or step in the floor even for this purpose.

The entire sufficiency of any one of the foregoing means of safety should not prevent the adoption of all the others. In this case we want the security derived from several concurrent certainties. I have gone much into detail in this, because it is the one vital thing. The platform once secure, there is no difficulty about anything else.

If it is suspected that the timber enclosed in cement may suffer from dry-rot, it should be previously steam seasoned and treated with creosote or some other preservative.

The form and dimensions of the platform are shown in sketch No. 2, Plate XIII.

Sketch No. 3, Plate XIV., is a section tranversely through the middle of the lock, showing the platform, the stop-water walls under it, and the walls upon it.

Beginning on the left side we have first the sustaining wall of the outside of the inlet channel, 10 feet thick at bottom, measured on the platform, 10 feet high on the back, supporting a slope wall laid in cement, resting on an inclined stratum of gravel or concrete. This sustaining wall should be perfectly water tight, and backed up by perfectly watertight puddling. The special risks to be most carefully guarded against when this plan is adopted, is the risk of the water getting around the edge of the platform, and so under it. Besides the stop-water wall under the edge of the platform, assurance may be made doubly sure by building another one under the main-wall. This sketch supposes the water to come into the inlet channel at right angles to, not alongside of, the lock from the head. The bottom of the inlet channel should in this case be 15 feet wide. If the water comes in from the head of the lock it should be 20 feet wide.

The main walls, as I shall call them, or side walls of the chamber are proposed to be 40 feet thick at bottom and 20 feet at top-water line, to batter 2½ feet (half an inch to the foot) on the face, and 17½ feet on the back. The water when the lock is technically empty being 30 feet deep, and the lift 30 feet, the height to top-water is 60 feet. The thickness is intentionally excessive (see note A). At the bottom next the face and at the angles and shoulders of the recesses and openings, the wall should be of large, dressed stone, all the rest good rubble, grouted or otherwise carefully insured against interstices. An interstice communicating with the high level counteracts half of the weight of the wall over it. As the best engineering is that which answers the purpose well at least cost, I would use no cut stone. One dollar spent in getting better cement, does more good than ten spent in dressing stone. Good cement with clean sand filling the whole space between the stones, makes the whole wall one great monolith.

Each main wall is pierced* with ten openings, each 8 feet wide and 12.5 feet high to the spring of the arches of the semi-cylindrical heads, each opening being 100 square feet at the throat. The outer end of these openings should be fan-tailed. Though large ships and steamers should

* Mr. Douglass emptied his locks through the side walls more than forty years ago.

PLATE XIV.
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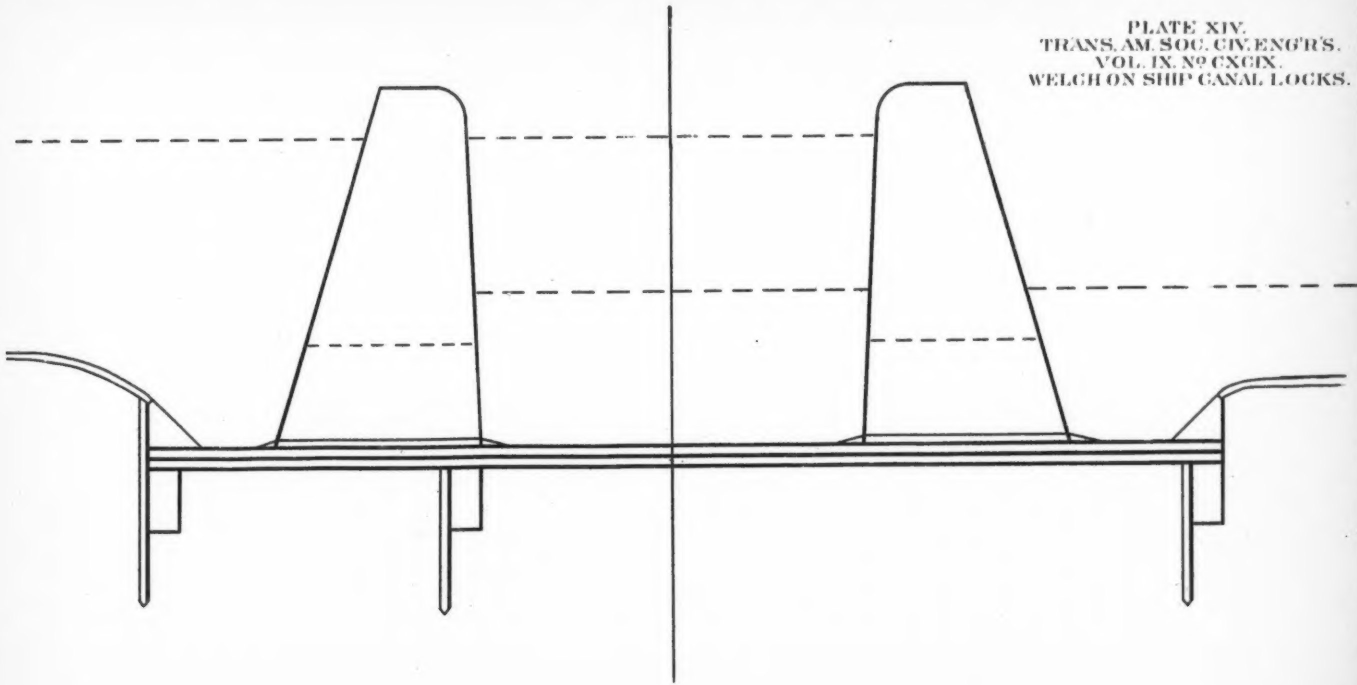

not be allowed to touch the wall, small vessels may, and with a view to their protection, I would cover the face of the wall with 4 or 6-inch plank of soft elastic timber. This, under the surface of the upper level, will last indefinitely. I have found this cheaper to maintain than cut faced ashlar —and far better for the vessels. If I had a lock already built with a cut stone face, and if it were wide enough, I would cover it over with plank. The finish of the top of the wall must be adapted to the machinery to be put upon it.

The width of the chamber is 75 feet on the floor, which makes the width at top-water when full 80 feet.

The bottom of the outlet channel is 20 feet wide, and the sustaining wall on that side 10 feet.

This makes the whole width of the platform $(10 + 15 + 40 + 75 + 40 + 20 + 10 =)$ 210 feet.

Sketch No. 4, Plate XV., is a longitudinal section along the axis of the lock at the upper end, showing a section of the breast wall, upper mitre sill, head wall and iron tube for passing the ropes from the engine to transmit the power to the other side of the lock, and the guard-gate to shut the water out of the lock when necessary. The tube is embedded in the masonry to protect it from accident. A space of several feet is left below the swing of the upper gates to enable the water to pass under as well as around them, and so diminish the resistance of the water to their rapid swinging.

The inlet gates, to admit the water into the lock, should be made to hoist and not revolve so that the current created shall strike under, not against the ship then in the lock, and so that it shall not send the current into the lock obliquely. The opening being 8×12.5 feet, the gates should be about $9.5' \times 12.63'$, making their outer surface 120 square feet. I would make the gate of 12-inch timber; battened on the lower side so that the grain of the battens should slide with the grain of the wooden posts against which the gates set. If the gates are of iron still the sliding parts should be wood. The power to move the gates should be in the same plane as the sliding surfaces. As the water presses on the top of the gate the bottom should be bevelled nearly to an edge at the lower side, so that the water shall also press up on the bottom. The stem and battens of these wooden gates should be fastened by $2\frac{1}{2}$-inch turned tree-nails, as well as by screw-bolts, so as to offer as much surface as possible to prevent the grain of the wood from crushing or com-

pressing by the shearing motion. The power to move these gates may be transmitted from the engine by hydraulic apparatus, or by ropes.

I have been accustomed to work gates larger than these, though not under so great head, by screws worked by hand. I propose for these gates, screws of 2-inch pitch, fixed to the stems of the gate (their axis being, of course, in the same plane with the sliding surfaces of the gate), passing vertically through thick nuts resting on the wall. Either the screw or nut may be made to revolve ; whichever revolves will be turned by ropes from the engine around vertical drums. A dry well may be made for the screw, the stem passing through a stuffing box.

The area of the orifice is 100 square feet, but the area of pressure against the gate is 120 square feet under 30 feet head. This makes a pressure of $(120 \times 30 \times 62.5 =)$ 225 000 pounds. If the wood of the sliding surface is thoroughly saturated with tallow, the effect of which lasts a long time, the friction will not exceed one-eighth of the pressure. One-eighth of 225 000 is 28 125 pounds, the power required to overcome the friction. Add to this the weight of the screw and stem, and that of the gate less its buoyancy, say 3 875, bringing required power up to 32 000. Add for friction of the screw, &c., 50 per cent., bringing the requirement of power to raise the gate up to 48 000 pounds. To raise the gate one foot in three seconds the expenditure of power is therefore 16 000 foot pounds per second for each of the ten gates. To raise it one foot requires six revolutions of the screw or nut. If the drum is 30 inches in diameter or 7.5 feet circumference, the rope moves $6 \times 7.5' = 45'$ to raise one foot, and if this is in 3 seconds the rope moves 15 feet per second. The strain upon the rope is $\frac{48\,000}{45} = 1\,066.66$ pounds. For this a half-inch rope is sufficient. Of course there must be two ropes from the drum to the engine—one to raise and one to lower. There should not be one endless rope, as it may slip, and render the action uncertain, but separate ropes each attached to the drum. The height of the drum to raise the gate 12.5 feet must be $(12.5 \times 6 \times 0.55 =)$ 41.25 inches, say, 3.5 feet. The whole movement of the rope is about 560 feet. If the above motion of the screw is too rapid the pitch and the size of the rope may be increased.

The whole amount of power required to raise these gates simultaneously one foot in three seconds, when the resistance is greater is $(16\,000 \times 10 =)$ 160 000 foot pounds per second.

Such gates commonly require no repairs for years.

PLATE XV.
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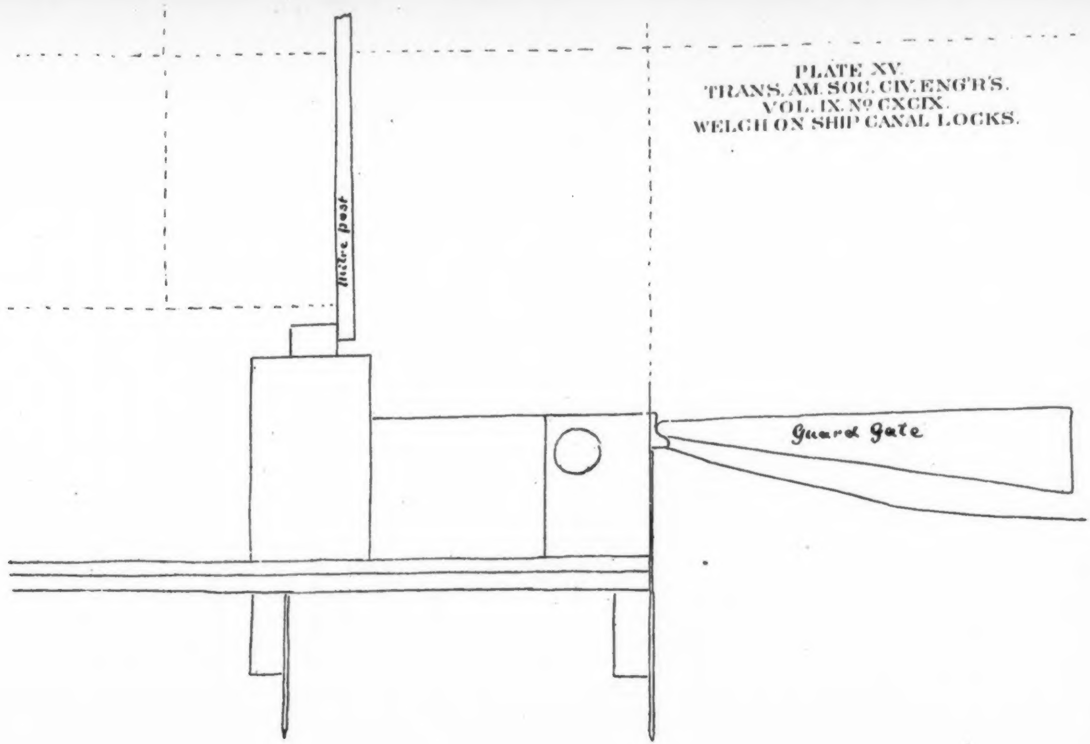

The outlet gates may be revolving valves 8 feet wide and 12.5 feet high at the edges, with semicircular top conforming to the arch. The preponderance of hydrostatic pressure on one side may be nothing, but the dynamic preponderance in certain positions may be considerable. It is safest to provide for 10 000 pounds with 4 feet leverage. Suppose the gate worked by a fan-shaped lever 20 feet long, then it requires a force of $(4 \times 10\,000 \div 20 =)$ 2 000 pounds to hold it. To be safe against sudden jerks this should be held by inch ropes to a drum 3 feet in diameter one first passing around a sheave. To open or shut the gates requires $\left(\frac{20 \times 2 \times 3}{4}\right) \div (3 \times 3) = 3.33$ revolutions of this drum. The power may be transmitted from the engine by half-inch ropes passing round a drum on the same shaft 6 feet in diameter; the strain on these is 1 000 pounds. If the gate is shut or opened in 10 seconds the motion of the transmitting rope is $\frac{3.33 \times 6 \times 3}{10} = 6'$ per second.

To prevent wearing the foundation platform the bottom of the inlet and outlet orifices may be covered by hard wood plank with a stratum of mortar between it and the plank under it. The grain should be across the cement.

The main gates may be of timber, the arms curved as in the English docks, and trussed besides, bow string fashion. When the gate is shut the curved bottom arm should rest against a curved mitre sill, or else the planking be altogether on the chords, otherwise there will be a strong upward pressure on the bottom of the gate when the head is on, not there at other times. The weight should not be supported on rollers under the gate, but by the regulated buoyancy of an air vessel between the curved arms and the chords, or by a counter weight at the end of a strongly trussed balance beam. The pivot of this beam should rest on an iron bridge over the axis of the quoin post, not on it, so as to avoid bringing too great weight on the pivot at the bottom of the quoin post. The gates should work in wooden hollow quoins, not stone or iron, which cause so much friction and wear.

Most of the damage to ordinary locks, and most of the cost of repairs, come from the slamming of, or collisions against the gates, and from the wickets in them getting out of order. The slamming is caused by letting on water to save labor. There is no temptation to do this when the gates are shut by steam without labor. The collisions can be prevented

by hauling and handling the ships by the cable worked by steam. Costly maintenance of wickets is avoided by having none in any of the gates. In fact, with the plan now proposed, all causes of damage to the lock itself are avoided.

The weight of water 30 feet deep in the sector through which the main gate swings, is about 2 000 000 pounds. If the gate is opened or shut in 40 seconds, then, to overcome the inertia of this water and send it round to the opposite side of the gate, and create all the other unavoidable currents, and overcome all friction, I estimate to require 80 000 foot pounds, or 2 000 per second. If the gate is moved by a fan-shaped lever 20 feet long, the strain upon the rope is 4 000 pounds, and its movement is about half a foot per second. An inch rope may be used to bring the power from the engine, or the inch rope may pass around a drum 3 feet in diameter, and a half-inch rope around a 12 feet drum, on the same shaft, may bring the power from the engine.

To overcome the inertia of a ship weighing 40 000 000 pounds, and give it a velocity of 3 feet per second in 60 seconds (neglecting at present the resistance of the water) requires ($32 : 40\ 000\ 000 : : \frac{3}{60} :$) 62 500 pounds strain on the hauling cable. At the close of the 60 seconds the power expended is 187 500 foot pounds per second, though when 3 feet velocity is established it will take less than 100 000 foot pounds per second to maintain it. To transmit this power requires a rope 3 inches diameter, and the drum around which it passes must be 9 feet in diameter.

The water immediately above and below the locks should be wide and deep, so as to give as little resistance as possible to the motion of the ship. On the canal of which I once had charge I deepened 2 feet or 3 feet above and below the locks.

The hauling cable should pass from the drum that moves it up and down parallel to the lock to sheaves a little over 2 500 feet apart, making the whole length a little over 5 000 feet. About half of this length, along the face of the lock wall, so located as never to reach the drum, and to which part of the rope the ships are to be fastened, should be enlarged to 5 or 6 inches diameter, or rather to a flat rope $2\frac{1}{2} \times 12$ inches, so as to have, besides the strength to haul, the strength to stop a ship by the application of a brake. The sheaves around which this enlarged part passes should be 20 feet diameter, or more. This enlarged part passes through brakes formed with short endless bands passing around the brake blocks over and under the cable, the bands being carried along by

the cable so as not to chafe it, to be operated by ropes from the engine. Probably their application to stop a ship may not be required once a year, but they should be used constantly to hold the ship still. This part of the cable will bear a strain of 200 000 pounds, and this is sufficient to stop a ship weighing 40 000 000 pounds and going 5 feet per second in 30 seconds, or if the velocity of the ship is 3 feet per second in less than 20 seconds, and in less than 30 feet.

The ship may be connected with the hauling cable by two short hemp cables 5 inches diameter, one leading forward from the ship's bow, the other aft from her quarter. These should be handled and passed over the ship's side by light shears or derrick booms. They should be hooked to securely-fastened cables on board, either belonging to the ship or furnished to it as it enters the canal and given up as it leaves.

As the engine does only one thing at a time, the greatest amount of work required of it is that which will perform the heaviest single operation, which is moving the hauling cable three feet per second, requiring 187 500 foot pounds per second. The next greatest is to raise the inlet gates, requiring 160 000 foot pounds per second.

I propose an engine of two cylinders, each 24×42 inches, with 50 pounds effective mean pressure on the pistons throughout their stroke, the pistons, when doing full work, moving 7 feet per second, giving to the engine one revolution per second. The power developed per second is $(2 \times 50 \times 7 \times 24 \times 24 \times .7854 =)$ 316 673 foot pounds. If 40 per cent. is lost by friction of the engine and in the transmission by the ropes, we have left available at the points where the power is to act about 190 000 foot pounds per second.

The hauling cable drum having 9 feet diameter, or 27 feet circumference must revolve once in 9 seconds to give the rope and the ship a velocity of 3 feet per second, so the engine must make 9 revolutions while this drum makes one; and the ship moves 3 feet, while the piston moves 7 feet. I would have an intermediate shaft worked by the pinion on the crank shaft, making one-third as many revolutions as the engine, which I will call the working shaft, and which always moves when the engine moves. This drives the cable drum shaft, the connections being made and unmade by a suitable clutch. The motion of the cable is reversed by reversing the engine.

The two ends of the cable being attached to opposite ends of the

drum, the two parts alternately occupy the intermediate space. The drum must then be about 22 feet long.

It will not do in this case to use endless ropes and rely upon friction.

The drums which move the ropes that work the inlet gates may be loose on a shaft of their own and worked from the working shaft, being thrown in or out of gear and their motions reversed by V-shaped friction clutches. If these drums are 5 feet diameter they must make one revolution per second (3 times as many as the working shaft), and the length of each drum to hold the two ropes (each moving about 560 feet) is $\left(\frac{560}{15} \times 0.55 =\right)$ a little over 20 inches. The object of making these drums so large is to avoid excessive length of the shaft, around, but not fast to, which they revolve. Each of the ten drums is connected with the working shaft by separate clutches, but, as they will nearly always work together, the separate levers can all, or any part of them, be moved by one common handle.

Breast lines, to haul or hold the ship in the right place, should be operated by the engine, and moved along by it as the ship moves. There are several ways of doing this. I will tax your patience by describing only one.

The breast lines may be hauled and moved along as the vessel moves by apparatus similar to the travelling cranes at Crewe and at Altoona, used for lifting and handling locomotives. This apparatus may move lengthwise of the lock on a railway in a longitudinal depression or continuous pit 2 feet deep on the top of the side wall, and for 800 feet or 1 000 feet above and below the lock on piers or trestles well tied back to the land. These railways need not be straight nor parallel to the centre line of the lock, though they should be as nearly so as practicable. The pen and ink sketch, No. 5, Plate XVI., shows the position of some of the more important parts. The rails in the bottom of the pit are represented by *rr*. The wheels on the plan (not shown in the end view) are represented by *WW*. To avoid multiplying lines the frame is not shown, except the bottom plate in the end view. The very heavy horizontal strain upon the frame, caused by hauling the breast lines, comes against a rail, *T*, set with its base against the shoulder of the pit, bearing against which the two double-flanged horizontal wheels, *HH*, sustain the sideways pressure. To prevent the leverage of the strain upon the breast line from causing the apparatus to revolve around *T*, the other side of it is

PLATE XVI.
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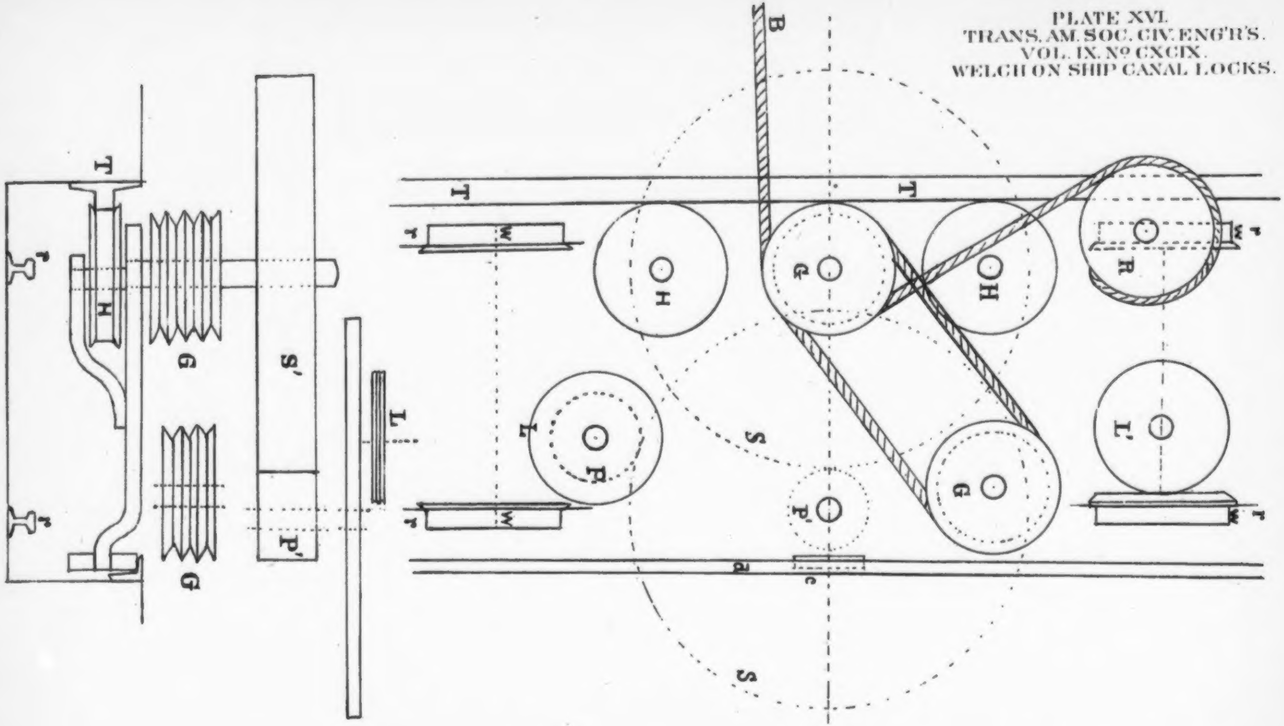
WELCH ON SHIP CANAL LOCKS.



kept from rising by a roller, *C*, under a flange, *d*, fastened to the other shoulder of the pit.

The endless ropes that bring the power to operate the apparatus may be less than an inch in diameter, of cotton or linen, passing around sheaves at each end of the railway travelled over, and should move with great velocity. The part of the power rope moving towards the engine may pass around the loose pulley, *L*, which, when necessary, may be made fast by a friction clutch so as to turn the pinion, *P*, driving the spur wheel, *S*, on the same axle as the pinion, P^1, driving the spur wheel, S^1, on the same axle as the grooved wheel, *G*, which hauls the breast line, *B*. The stray end of this line may be taken up on a reel, *R*, to which power enough should be applied by hand or by a belt to keep the line taut, so as not to slip in the groove. Of course the part of the line that reaches the grooves should be of some pliable material, not wire. The part of the power line moving from the engine may pass around a loose pulley, L^1, which may be made fast by friction clutch, and made to move the apparatus over the railway, a bevel pinion driving a bevel wheel on the flange side of the wheel *W*.

To perform all the operations other than hauling the ships and raising the inlet gates the motion of the engine may be very slow, and the steam in the cylinder at very low pressure. The drums for all these operations may work loose on a shaft on the side of the working-shaft opposite to the drums that work the inlet gates, and be connected by *V* clutches. The apparatus is so simple, and so like that already described, that further description is unnecessary.

Where the changes in temperature are great, tightening pulleys may become necessary, though I have always found the weight of the ropes themselves sufficient.

The engine should be near the head of the lock, as the tube through which the power is carried to the other side is at the head. It should be on the side where the most power is used; that is, the side where the hauling cable and the inlet gates are.

The engine and all the clutches should be handled by one expert, standing on an elevated, sheltered, glass-sided observatory, projecting out over the face of the lock wall, with the levers and handles and connecting links and hooks all within his reach without changing his position or even looking around. Just this has been successfully done for a dozen years, though not on so large a scale.

The whole number of levers in ordinary use will be (throttle, reverse, cable drum clutch, brakes 4, main gates 4, inlet gates 10, outlet gates 10, breast lines 4 =) 35. But they may be so connected as to be commonly worked by 15 handles.

It may be well to have indicators or marks on the ropes to show when the operation is about to be completed.

Though the expert has so many things to do, and so many levers to handle, he is in no danger of becoming confused, for, with only one or two rare exceptions, only one operation is ever going on at a time.

In addition to these daily operations provision should be made, by suitable connections with the engine, to raise the guard gates at the heads of the lock and of the inlet channel, and, with shears or derricks, kept on hand, to lift out and replace the main gates, and the inlet and outlet gates, and to handle coffer dams, should they ever be required, and to pump out the water. One extra drum at the engine would answer all these purposes in succession.

It may be objected that with so much apparatus something is always liable to go wrong and interrupt the navigation. Apparatus not more simple, and working under disadvantage, because the locks were not calculated for it, has been in operation a dozen years, and, so far as I know, it never got out of order so as to cause an hour's delay. Multiplicity is not complicity. Bell wires or telegraph wires do not work badly because there are many of them.*

Hundreds of things are in constant use more complicated and more difficult to operate, in many of which failure would be more disastrous. The application of steam to operate locks is no longer an experiment.

I have all along intentionally overestimated the frictions and strains, and calculated for excessive power and strength.

I have supposed the power transmitted by ropes. A better way may be by hydraulic apparatus. Then water power, if it is to be had, could do the pumping; or if steam is used a much smaller engine would be sufficient. I have not undertaken to describe or decide upon the best plans, but to give plans that are practicable—to show that locks for the largest ships can be made, and safely and expeditiously operated, at a

* Many years ago I pumped the water from a wet excavation on one side of the Delaware by water power a thousand feet distant on the other side, carrying the power across the river by a rope supported on triangles made of saplings cut from the woods. Almost any one of the operations proposed is easier than that, and of much the same kind.

cost which, though great, and at a moderate delay, and without danger, is as nothing compared with the cost, danger and delay which has been proposed to be incurred to avoid them.

When water is scarce one or more water saving basins may be used. Each should have a surface eight or ten times as great as the lock chamber. The communications between them and the chamber may be by large pipes resting on the foundation platform, passing through the outlet or inlet channels, or both of them, the last instalment of discharge when emptying, and the first when filling, being through other openings in the wall into or from the space over the tops of those pipes.

The time required to pass the lock after the ship has come to, may be estimated as follows:

To hook on the hauling and breast lines	1	minute.
To give velocity of 3 feet per second in 135 feet	1.5	"
To move 540 feet at 3 feet per second	3	"
To stop in 135 feet	1.5	"
To shut the lower gates	1	"
To fill the lock safely (outside calculation)	6	"
To open the upper gates	1	"
To overcome the inertia and move 810 feet	5.5	"
	20.5	"

A ship going down could pass two or three minutes sooner, as the lock can safely be emptied in three or four minutes. The lock, with no vessel in it, can be filled or emptied in two minutes. A vessel going up should be held near the outlet side of the lock, going down near the inlet side.

I should estimate the whole detention of a large ship by a lock at something less than half an hour, of a smaller vessel or any steamer at considerably less.

The cost of such a lock in this country, under favorable circumstances, might be about as follows, where no piling is necessary:

Excavation of pit, say $900 \times 270 \times 40 \div 27 = 360\,000$, at 50c	$180 000	
Pumping and bailing	20 000	
Carried forward		$200 000

Brought forward		$200 000
Concrete foundation, $750 \times 210 \times 2 = 315\,000$ cu. ft., at 0.2	$63 000	
Timber platform, $750 \times 210 \times 2 = 315\,000$ cu. ft., at 0.6	189 000	
Stop-water walls under foundation, $3\,000 \times 5 \times 8 = 120\,000$ cu. ft., at 0.25	30 000	
		282 000
Main walls, $2 \times \frac{40+18}{2} \times 66 \times 750 = 2\,871\,000$ cu. ft., at 0.2	$574 000	
Cross walls, about $600 \times 60 \times 15 = 540\,000$ cu. ft., at 0.2	108 000	
Sustaining walls for channels, $10 \times 10 \times 500 = 50\,000$, at 0.2	10 000	
		692 000
Main gates and appurtenances, $4 \times 50 \times 60 \times 2 = 24\,000$ cu. ft., at 1.00	$24 000	
Inlet and outlet gates, screws, &c	25 000	
Ropes, sheaves, &c., &c	40 000	
Engine, boiler, and machinery about it	40 000	
		129 000
Unestimated items and contingencies		300 000
		$1 603 000

Where any such lock is likely to be built, it is likely to cost $2 000 000. When piling is required it may cost $200 000 more.

The annual cost of maintenance and operation of the lock may be as follows :

Repairs and renewals of engine, machinery, ropes, gates, &c., 12 per cent. on $130 000	$15 600	
Other possible repairs	4 400	
		$20 000
Coal for engine at full work only a very small part of the time may be 1 000 tons, $6.00	$6 000	
Superintendent, $2 000 ; 3 experts, $3 000 ; 3 machinists, $2 000 ; 3 firemen, $1 500 ; 30 other men, $12 000 ; extra man, $500	21 000	
Other expenses	3 000	
		30 000
Total being about the interest on $700 000, at 7 per. cent		$50 000

So we may say in round numbers that on the great American Isthmus, the cost of the lock, and the sum of which its maintenance and operation equal the interest, amount, all together, to $100 000 per foot lift, unless the lifts are low, which probably never need be.

Probably in almost every location where water is to be had, a better ship canal can be made with a few locks, and at far less cost, than a sea level canal. A small part of the money saved by the locks will in most cases make a broad and deep canal, where ships can go safely and rapidly, and pass each other anywhere, without delay ; instead of narrow, deep cuts, commonly dangerous and always expensive, where ships must move slowly, and commonly wait to pass each other.

The question must be decided in each case, whether the very large amount required for the construction and operation of a lock will save a larger amount in some other way, and whether the half hour's delay at each lock will save a greater delay in some other way.

The plan I have presented of the construction and operation of a ship-canal lock, is so simple, and its practicability so evident, your mental exclamations have probably so often been "why, of course," that I feel like apologizing for taking up your time in laying it before you. And yet, though so plain when once presented, eminent engineers have failed to see it.

Perhaps ship-canals may give way to ship railroads, as proposed by our honored Chairman. I have not gone into the railroad calculations, and have at present no opinion to express on that subject.

NOTE A.—*Stability of the Main Walls.*—The pressure tending to overturn the wall is $\left(30 \times \frac{30}{2} =\right)$ 450, with a leverage of $\left(30 + \frac{30}{3} =\right)$ 40 feet ; the product is 18 000 ; and $(30 \times 30 =)$ 900, with a leverage of 15 feet, the product is 13 500. Add together these two products, and the whole tendency to overturn the wall around the bottom angle is represented by 31 500. The unit being the weight of a cubic foot of water.

The section of the wall may be divided into two triangles and a rectangle between them. The tendency to prevent overturning will be as follows : Front triangle $\left(2.5 \times \frac{60}{2} =\right)$ 75, with leverage of $\left(2.5 \times \frac{2}{3} =\right)$ 1.66, making the product 125 ; the rectangle is $(20 \times 60 =)$ 1 200, and the leverage $\left(2.5 + \frac{20}{2} =\right)$ 12.5, and the product is 15 000 ; the other triangle $\left(17.5 \times \frac{60}{2} =\right)$ 525, and the leverage $\left(2.5 + 20 + \frac{17.5}{3} =\right)$ 28.33,

the product is 14 875. The sum of these three products is 30 000. Call the specific gravity of the masonry 2, and we have 60 000. Add for the water over the third triangle $\left(17.5 \times \frac{60}{2}\right)$ 525, with leverage of $\left(2.5 + 20 + 17.5 \times \frac{2}{3} =\right)$ 34.16, which makes 17 937. Then the resistance to overturning is represented by 77 937 neglecting the weight of the water over the front triangle. This $\div$ 31 500 = 2.47 the factor of safety against overturning around the bottom angle. It can, therefore, only give way from disruption by the shearing effect of the pressure, and that is not possible if the wall is grouted, and the cement is good.